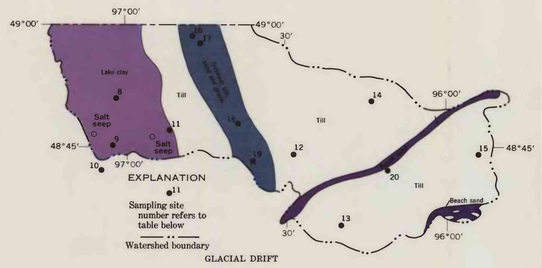
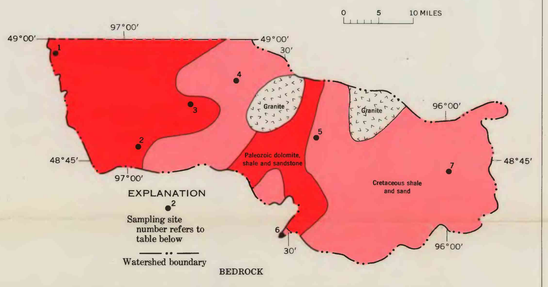
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH
THE MINNESOTA DEPARTMENT OF CONSERVATION
DIVISION OF WATERS

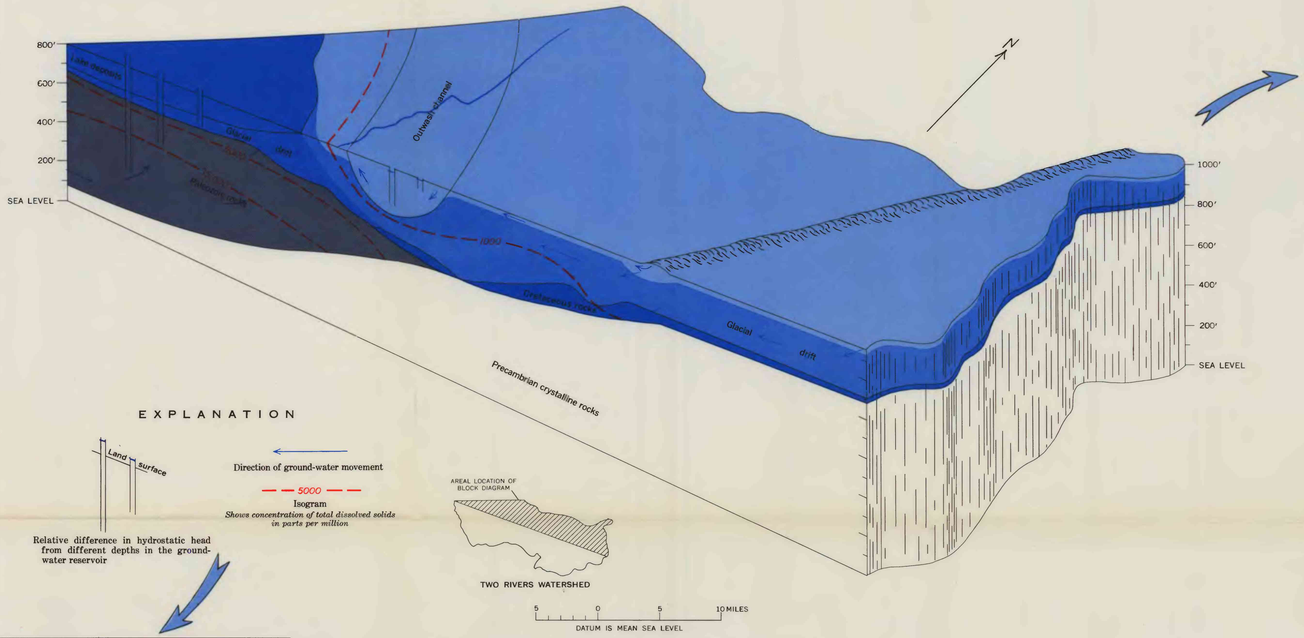
HYDROLOGIC INVESTIGATIONS
ATLAS HA-237 (SHEET 4 OF 4)

GROUND-WATER MOVEMENT AND WATER QUALITY





SELECTED SITES WHERE WATER SAMPLES FOR CHEMICAL ANALYSIS WERE OBTAINED



GENERALIZED HYDRAULIC AND GEOCHEMICAL CHARACTERISTICS OF GROUND WATER

Geologic unit and predominant anions	Geologic environment	Geochemical interaction	Water movement
Shallow drift and outwash channel (bicarbonate)	Near surface, weathered zone in surficial till and surficial beach and channel deposits largely in the central and eastern part of the watershed. These deposits contain soluble carbonate minerals. Sulfate minerals have been largely removed by solution	Leaching of carbonate minerals. High concentration of organic acids and CO_2, which forms carbonic acid, in the soil zone chemically reacts with the carbonate minerals resulting in rapid increase in Ca^{+2}, Mg^{+2}, and HCO_3^{-1} ion concentration. Sulfate content is commonly reduced in swamp, peat bogs, and deeper part of channel deposits. Relatively low dissolved solids in water indicates a relatively short period of time water is in contact with minerals	Ground water is near a source of recharge—water has been in the ground for a relatively short time. Surface water in tributary streams during periods of low flow is the calcium-magnesium bicarbonate type indicating that ground-water movement is relatively rapid through the upper parts of the ground-water reservoir and is discharged locally
Deep drift (bicarbonate and sulfate)	Buried unweathered till in the eastern part of the watershed. Till contains fragments of limestone, dolomite, anhydrite and gypsum. Organic matter occurs locally	Continued solution of carbonate minerals. Increase in sulfate ion concentration due to solution of highly soluble sulfate minerals Locally, sulfate concentration is reduced by anaerobic bacteria in presence of organic materials. Dissolved-solids concentration is approximately 1000 ppm or less	Lateral movement is westward toward discharge area
Drift overlying Paleozoic rocks (sulfate and chloride)	Till and lake deposits in the western part of the watershed. Lake deposits contain clay which has high ion-exchange capacity	Mixture of chloride type water from underlying Paleozoic rocks and magnesium-calcium-sulfate type water from deeper zones in the glacial drift. In the lake deposits, water at shallow depths is commonly harder than water in the deeper zones because of ion exchange which results in a high concentration of Na ion in the deeper water Dissolved-solids concentration generally between 1000 and 5000 ppm	Ground water is in discharge area of the watershed. Dominant movement is upward at a very slow rate, from deeper zones in the ground-water reservoir. Lateral movement is extremely slow also
Cretaceous rocks (chloride and bicarbonate)	Cretaceous sandstone and shale in the central and eastern part of the watershed. Shale contains clay minerals, sandstone contains lignite fragments, both of which commonly have high ion-exchange capacity	Ion exchange softens water that moves from the overlying glacial drift into the Cretaceous aquifers. Sulfate concentration is lowered by reduction Dissolved-solids concentration less than 2000 ppm	Slow lateral movement in eastern part of basin. Chloride water from Paleozoic rocks moves upward and mixes with water from Cretaceous rocks near the Lake Plain
Paleozoic rocks (chloride)	Paleozoic dolomite and sandstone. Contain large amounts of soluble minerals	Water is saline because of long period of contact with soluble rocks of this age underlying adjoining North Dakota and Canada Dissolved-solids concentration generally greater than 5000 ppm	Slow upward movement. The water is trapped under nearly impermeable lake clay, therefore natural discharge of the aquifer is very slow

Evaluation of the ground-water system depends upon knowing where water enters, how fast it moves through, and where it leaves the ground-water reservoir. Movement of ground water is controlled by the geologic units that make up the reservoir.

Water is a solvent that is in motion within the ground-water reservoir and tends to approach chemical equilibrium with the materials in the reservoir. Because of this continuous chemical change toward equilibrium, water quality information provides a basis for the interpretation of movement of water in the ground-water reservoir. Chemical changes in water type (the dominant ion or ions in solution) and total dissolved solids were used to interpret water movement in the Two Rivers watershed. Total dissolved-solids concentration depends upon the occurrence and relative solubilities of minerals within the ground-water reservoir, chemical interaction, and the length of time that water remains in contact with these minerals (for example, water with the least dissolved-solids concentration occurs in permeable materials near recharge areas). Schoeller (1959) has shown that, on a regional scale, composition of ground water changes to approximate that of sea water as it moves from recharge to deep stagnant areas. The full sequence of predominant ions is:

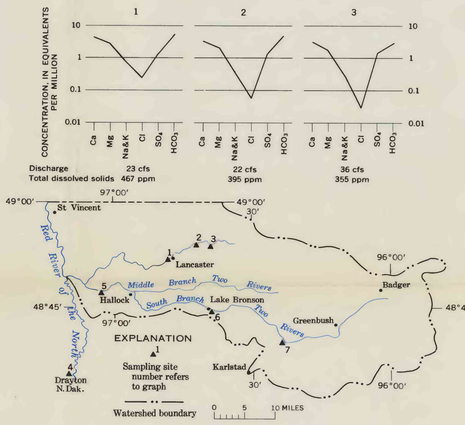
$HCO_3^{-1} \rightarrow HCO_3^{-1} + SO_4^{-2} \rightarrow SO_4^{-2} \rightarrow SO_4^{-2} + Cl^{-1} \rightarrow Cl^{-1} + SO_4^{-2} \rightarrow Cl^{-1}$

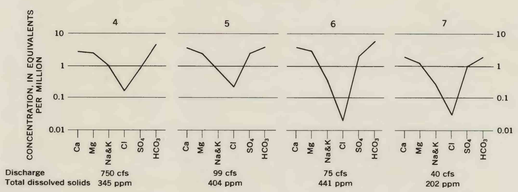
In smaller areas, as the Two Rivers watershed, the sequence may not be complete or may be masked by large contributions of ions from a particularly soluble mineral. Where several aquifers occur within the ground-water reservoir, and the aquifers are hydraulically connected, the quality of water may reflect mixing of the waters.

In the Two Rivers watershed the normal sequence of predominant ions in water moving through the glacial drift from the eastern area westward is:

$HCO_3^{-1} \rightarrow HCO_3^{-1} + SO_4^{-2}$
(shallow zone) (deeper zone in drift in eastern part of watershed)

The sequence is modified where the water moving from the drift into the underlying Cretaceous deposits in the eastern part of the basin is affected by sulfate reduction. The sequence is also modified in the western part of the basin where chloride water from the underlying Paleozoic rocks moves upward and mixes with the water in the glacial drift.





CHEMICAL QUALITY OF SURFACE WATER IS RELATIVELY UNIFORM IN THE TWO RIVERS WATERSHED.—*The water is hard and of the calcium magnesium bicarbonate type. It is suitable for municipal supplies and agricultural uses*

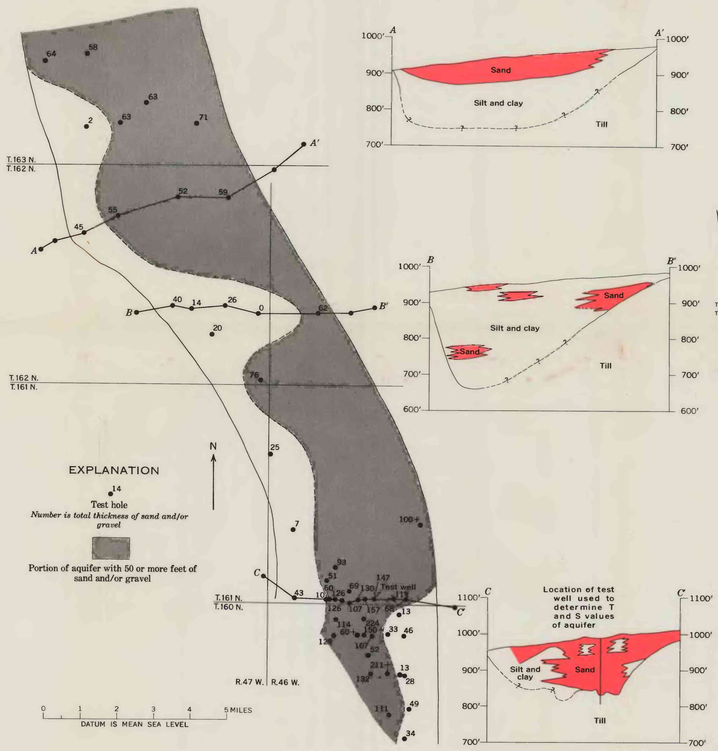
SIGNIFICANCE OF GROUND-WATER MOVEMENT TO WATER MANAGEMENT

1. The outwash channel is the most likely area for development of large amounts of water. Recharge in this area is relatively rapid and ground water can be salvaged from natural losses. Because water containing low dissolved solids moves from the surface into the highly permeable aquifer, heavy pumping should not result in deterioration of water quality. Water containing higher dissolved solids moves more slowly into the aquifer from the less permeable adjacent deposits

2. Lateral movement of underflow through the deep zone of the ground-water reservoir in the eastern part of the area is insufficient to maintain large yields from many wells. Sustained yield of drift wells depends principally upon vertical leakage that takes place in the vicinity of the well. Additional studies should be made to determine the rate of vertical leakage to the aquifer when water levels are lowered by pumping

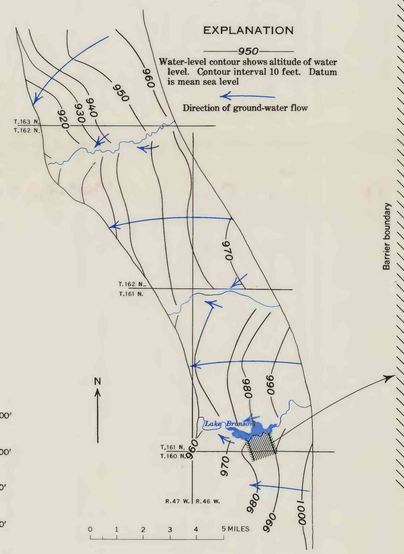
3. In the western part of the watershed, withdrawal from aquifers within the till will result in an increase in salinity. A reduction of artesian pressure will cause additional chloride water from the Paleozoic aquifers to move into the till

GEOLOGY



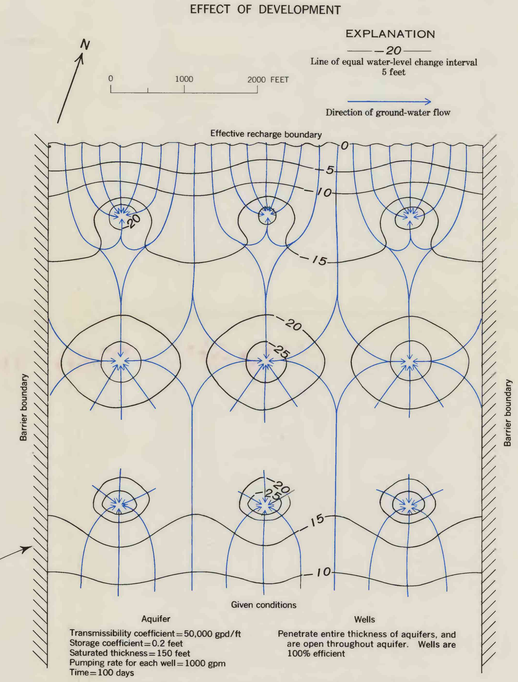
The most productive part of the aquifer occurs near Lake Bronson where saturated thickness of coarse sand and gravel is more than 150 feet. A large amount of water is stored in the less permeable sand, silt, and clay in the western part of the aquifer. This water will drain slowly to the more permeable deposits when water levels are lowered by heavy pumping

NATURAL WATER MOVEMENT



General direction of ground-water movement is westward. Locally, near streams, ground water is diverted toward stream channels. The water table is generally less than 5 feet below land surface, therefore evapotranspiration from the ground-water reservoir is large

EFFECT OF DEVELOPMENT



Substantial amounts of ground water can be developed near Lake Bronson from relatively few large yield wells. Substained yield would be largely maintained by recharge from Lake Bronson toward the wells. Computed water levels for given conditions in the aquifer after pumping 9 hypothetical wells at a rate of 1000 gpm each for 100 days is shown above. During this period 4000 acre-feet of water would be pumped. The actual water levels may be higher than those shown because the boundaries, which are based on geology, were located to show maximum declines. At the end of 100 days of theoretical pumping, water levels would decline and some water would be taken from storage within the aquifer. If the aquifer is not pumped for about a year, water levels would return nearly to initial position

THE SURFICIAL CHANNEL IS CAPABLE OF VERY LARGE YIELDS OF WATER.—*Largest potential yields are near Lake Bronson where surface water recharges the aquifer*

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C. —1967—W66253

WATER RESOURCES OF THE TWO RIVERS WATERSHED, NORTHWESTERN MINNESOTA

By
R. W. Maclay, T. C. Winter, and G. M. Pike

1967